RECTIFICATION OF RELIEF DISPLACEMENT ERRORS IN RADAR IMAGERY

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Abstract

One of the bewildering problems in topographic mapping from side-looking radar is the removal of the geometric error caused by radar relief displacement (or lay-over). During the last fifteen years this remained a major problem to overcome in attempting mapping from side-looking radar imagery. The present paper reports on results of an experiment concerned with digital monoplotting from side-looking radar imagery. An SLR image of a test area in Scotland along the banks of the River Tay was digitized and transformed to the ground system using mathematical transformation algorithms. A digital terrain model (DTM) was constructed from the existing medium scale map of the area and used to rectify the image data from the effects of radar relief displacement. The resulting tape is used as input to an automatic drafting machine to plot the rectified data in the terrain coordinate system. This plot is compared with both the topographic map of the area and another plot resulting from the unrectified image data. The results of the comparison show that it is indeed possible to substantially reduce the amount of radar layover by using the technique of digital monoplotting. However, the problems of radar image interpretation still set limit to the complete success of the technique.

Introduction

Digital monoplotting is the technique of measuring image coordinates on a single photo (or image) and rectifying and transforming them to the ground system. In conventional photogrammetric work, the technique utilizes values of the exterior orientation parameters (derived from space resection or aerial triangulation) and information on ground relief (obtained from a digital terrain model).

A digital monoplotting system consists mainly of three units.

(i) a measuring unit;
(ii) a digital computer; and
(iii) an automatic x/y drafting machine.

Since side-looking radar (SLR) geometric characteristics are entirely different, the concept of digital monoplotting from SLR images is one which needs further investigation.

Early Developments of Digital Monoplotting Systems

Two early digital rectification systems for plotting detail from single images were produced by Bendix Corporation (USA). These are the Bendix Line-rectifier LR-1 (Forrest and Hattaway, 1968) and the LR-2 (Forrest, 1972). They had been produced for the U.S. Navy for plotting on a point-by-point basis.

The Rome Air Development Center (RADC) of the United States Air Force developed a digital monoplotting system based on the use of a Calma 303 cross-slide digitizer and a Concord Cartographic Digitizer Plotter (CDP) attached to a PDP-9 computer (Hall,1974).

Another interesting application of the digital monoplotting technique was carried out at the ITC (Netherlands) by Besenicar (1976) for the purpose of investigating the possibility of revising cadastral maps from aerial photographs.

In all these photographic applications of the digital monoplotting technique, the input data to the system is the digitized measurements made on the aerial photograph. The camera orientation parameters are computed (using space resection) from the comparison of the measured image and the known terrain coordinates. From the available large or medium scale topographic maps, a digital terrain model (DTM) is generated by tracing contours on the maps and interpolating the heights into the rectangular array of the DTM. Thus, if a feature has to be plotted from a new photograph to update an existing map, then as it is traced on the photograph, its position is continually rectified for tilt and relief using the camera orientation parameters and the height interpolated from the DTM. The result of this process is a tape containing digital information of the new cartographic features which can be processed and edited prior to its final plotting.

The extension of the digital monoplotting concept to remote sensing was first carried out by Raytheon Automatic, under contract to the USA Engineer Topographic Laboratories (ETL), (Greve and Cooney, 1974). The result of this contract project was a procedure which allowed digital rectification of side-looking radar imagery to be carried out. The method is extremely complex and wholly dependent on the special circumstances of the test in which the aircraft positions and velocity and the time and range marks on the SLR imagery were all available. With most SLR imageries, however, this type and range of data is simply not available. This is indeed the case with Seasat SAR system whose imagery is used in this experiment.

Digital Monoplotting from Seasat SAR Imagery

The only known published work (at least to the present author) on digital monoplotting from Seasat SAR inagery is that carried out over a test area in East Anglia in England (Ali, 1986). The image of the test area was digitized and transformed to the ground system using a pair of higher order polynomial transformation equations.

In a single radar image, these transformed coordinates must contain certain planimetric errors in the range-direction due to changes in the topographic relief. If the ground track of the vehicle is not aligned with the north direction of the national grid system, then this error in the range direction will affect both computed eastings and northings of points depending on the azimuth angle between the ground track and the north direction. The unrectified data of the East Anglian Test image was plotted using a FORTRAN IV computer program.

The planimetric error in range of each point is given by:

$$\delta = -\frac{Hh}{s_g} \quad \ldots\ldots\ldots\ldots \quad (1)$$

where H = flying height
h = height of a point above average ground level;
and s_g = the ground range measured from the ground track to the point in question.

Since H and s_g can be assigned approximate values (e.g. the average flying height for H and the average distance between the ground track and the centre of the swath for s_g), a DTM can be constructed from existing topographic maps of the area and be used to compute the height h which will allow computation of δ in equation (1). This can be resolved into eastings and northings components using the azimuth angle between the flight direction and the National Grid North. This will result in corrected planimetric coordinates for each measured point with the relief displacement errors either eliminated or substantially reduced.

The results obtained with the East Anglian test image were extremely hampered by the problems encountered in the radar image interpretation. Few definite features were detected and identified on the radar image; and many roads of varying categories, settlements, woods, power lines, hydrographic features etc. were difficult to identify with conviction. In fact, some of these features were wrongly identified on the image. As a result of this, the final plot of the rectified SAR image did not fit the topographic map as well as was hoped for. On the other hand, the East Anglian test area was rather on the flat side which meant that radar relief displacement errors might well have been swamped by detection, identification and plotting errors. It is also possible that since the errors due to relief displacement are small (one resolution element or so) the final plotted map of the rectified data needed to be shown at a larger scale than that at which it was plotted (1:63360).

As a further investigation of the applicability of the digital monoplotting technique to SAR mapping, a Seasat SAR image covering areas along the banks of the River Tay in Scotland including the towns of Dundee and St. Andrews was selected for the purpose. The image was acquired from Seasat orbit number 762 and had been digitally processed by DFVLR at Oberpfaffenhofen in West Germany. Geometrically speaking, this particular image is superior to other optically and digitally processed images of the same test area (see Ali, 1985, 1986). The image had a resolution of 25 m and was at a scale of 1:250,000. The test area itself is very varied with some cultivated areas, a good deal of undulating ground and some quite hilly areas. The ground relief ranges from sea level to around 350 m with root-mean square relief variation (as computed from identified image points) of the order of ± 70 m.

Construction of the Digital Terrain Model of the Test Area

Construction of the DTM of the area commenced by measuring the contour lines shown on the existing 1:50,000 scale Ordance Survey map of the area. A large format (92 cm x 122 cm) GTCO cartographic digitizer was utilized for this purpose. This device has a resolution (or least count) of 0.1 mm and is equipped with a dot matrix coordinate display and a keyboard for the entry of header codes, height values or some other information. For this particular experiment, the digitizer was interfaced to a Lear Siegler ADM-3A video terminal which allowed the display and checking of coordinates and header codes; and to an MFE-2500 digital cassette drive which acted as the data recorder for the storage of the digitized contour data.

First of all, the corner points of the area of the map to be digitized were measured on the GTCO digitizer. Comparison of their digitizer coordinates and the corresponding terrain coordinates allowed the computation of the transformation parameters which could be used to transform all the measured planimetric data to the terrain system. A series of points located along each contour line were then measured and digitized in a point-by-point mode. The sampling interval in this process was in the order of 2 mm. Each contour line was assigned its correct height value corresponding to its position in a series of boxes located outside the area of the map being digitized. After digitizing all the contour lines on the map, the positions of all the points on these contour lines were transformed to the terrain system using the already determined transformation parameters.

In most DTM construction methods, the next stage is the interpolation of the actual DTM heights from the digitized contour information in order to form a square, a rectangular or a triangular grid. This, however, has not being carried out in this experiment. Instead, the measured points lying along the contours actually formed the basic DTM itself and do not correspond to some pre-determined pattern. Such an arrangement is usually termed a string DTM. This of course cuts out the requirement for the interpolation of a DTM from the contour information but at the cost of more complex search and interpolation routines when direct interpolation of the height of a specific location from the string DTM is required for the purposes of rectification.

Measurement and Transformation of the Image Data

For measuring the image of the test area, a positive film transparency of the DFVLR image was first mounted on the 28 cm x 28 cm format Hi-pad digitizer which has a translucent surface and could be back-lit. A video terminal and a digital cassette drive were attached to the digitizer for the display and logging of the coordinate data respectively. Before measuring and digitizing the test image, it was necessary to interpret and delineate all image features to be plotted. This was carried out with the help of the topographic map of the test area and a 3x enlarged print of the image. All interpreted image features were then measured, digitized and recorded. During the process of digitizing the image, suitable header codes were introduced.

The next stage in the digital monoplotting experiment is to transform the digitized image data to the terrain system using suitable mathematical transformations. From previous experience with digital monoplotting from SAR imagery (e.g. Ali,1986), there were unexplained and uncompensated systematic errors present in the y-coordinate of the image data. Hence it was decided to extend the terms of the mathematical transformation in order to take the following form:-

$$X = a_o+a_1x+a_2y+a_3xy+a_4x^2+a_5x^2y+a_6x^3+a_7x^3y+a_8x^2y^2+a_9y^3$$

$$Y = b_o+b_1x+b_2y+b_3xy+b_4x^2+b_5x^2y+b_6x^3+b_7x^3y+b_8x^2y^2+b_9y^3$$

Where, X,Y are the terrain coordinates;

x,y are the corresponding image coordinates; and

a_i, b_i are the unknown transformation parameters to be determined by comparison of the known terrain coordinates of the control points and their corresponding image coordinates.

Rectification of the SAR Image

The next step in digital monoplotting from SAR imagery is to generate the rectified image data by using height values obtained from the DTM of the area, thus correcting for the errors caused by relief variations. For each image point, a single height value is interpolated from the DTM. Many techniques and algorithms exist for interpolating height values for specific positions from DTMs (e.g. Leberl, 1975). In this particular experiment, the method of the weighted arithmetic mean is employed.

The implementation of this interpolation method was carried out as follows (Fig. 1):

(i) The transformed image point P_j is first located horizontally within the DTM. A search zone of radius r = 300m around this point was then defined so that all the measured DTM points lying within this zone are also defined.

(ii) Let q_i (i = 1,N) be the N points in the DTM that lie near image point P_j. The elevations of these points are known.

(iii) Let the horizontal distance between q_i and P_j be d_{ij}. The elevation of point P_j can then be obtained by the weighted arithmetic mean interpolation according to the following formula:

$$h_j = \frac{\sum\limits_{i=1} Q_i \, h_i}{\sum\limits_{i=1} Q_i}$$

where, Q_i is a weight function chosen according to the formulae:

$$Q_i = \frac{1}{(d_{ij})^C} \quad \text{or} \quad Q_i = \frac{1}{(1+d_{ij})^C}$$

where, C = constant ranging between 1 and 2 (Leberl, 1975). This is applied to all N points. If it is required to speed up the interpolation process, N can be limited to the 3 or 4 points nearest to P_j.

Having obtained the height h_j for P_j, then it can be used to compute the relief displacement error δ present in the coordinates of the transformed image point P_j. This process is repeated for all image points. The final outcome is a file containing the coordinates of all transformed image points corrected for the effects of variations in terrain relief. This file then serves as input to the plotting program to generate the planimetric line map.

Results of the Digital Monoplotting Experiment

Before plotting the rectified image data, the planimetric coordinates of the thirteen control points used for the determination of the transformation parameters have been computed before and after rectification of relief displacement errors. The computed r.m.s.e. values in the X-direction improved from $\sigma_x = \pm 68$m to $\sigma_x = \pm 50$m. The improvement in the Y-direction is more noticeable i:e from $\sigma_y = \pm 71$m to $\sigma_y = \pm 40$m.

As another initial check, the discrepancies at the control points before and after rectification had been plotted as vectors. These vector plots showed that while the rectification did reduce the magnitudes of the errors due to relief displacement, some residual errors will remain. Most of these still point in the range direction, a characteristic noticed in all Seasat SAR images tested for geometric accuracy (e.g. Ali, 1985, 1986; Petrie et al, 1984).

The main objective of the present experiment is to produce a rectified planimetric map from the Seasat SAR imagery. The plot resulting from unrectified SAR data of the test area is shown as Fig. 1, while that resulting from rectified SAR data is included as Fig. 2. Both maps have been plotted at a scale of 1:50,000 to make the comparison with the 1:50,000 Ordnance Survey topographic map of the area.

When comparing the map obtained by plotting unrectified SAR data (Fig.) with the O.S. topographic map of the test area (Fig.), it is noticed that there is a clear misfit between the two figures. In particular, features such as the B945 road the Ta y Port, the Tentsmuir Forest etc , are in places well off target while most of the plotted woodlands do not register exactly with the topographic map of the area.

Comparison of the plot resulting from the rectified data with the topographic map shows that a clear improvement over the plot of unrectified data has been achieved; especially in wooded areas. This shows that by using the transformation techniques adopted in this study and the technique of digital monoplotting, satisfactory results compatible with medium or small-scale planimetric mapping can be achieved from side-looking radar imagery. This may be important for many developing countries where basic planimetric mapping is either very poor or completely absent, though a disadvantage in this respect relates to problems of transferring this advanced technology in the form of computers, digitizers, image processors etc. to the developing world.

Conclusion

The experiment was concerned with generating automatically planimetric maps from side-looking radar imagery. The digitized image was transformed mathematically to the terrain coordinate system and the transformed data was rectified from the effects of radar relief displacement by interpolating heights from a digital terrain model. The results show that it is indeed possible to produce such maps from SLR imagery with the effects of radar relief displacement either eliminated or substantially reduced. The remaining errors inherent in the imagery may be due to mis-identification of features known to be on the ground but are difficult to define exactly on the image.

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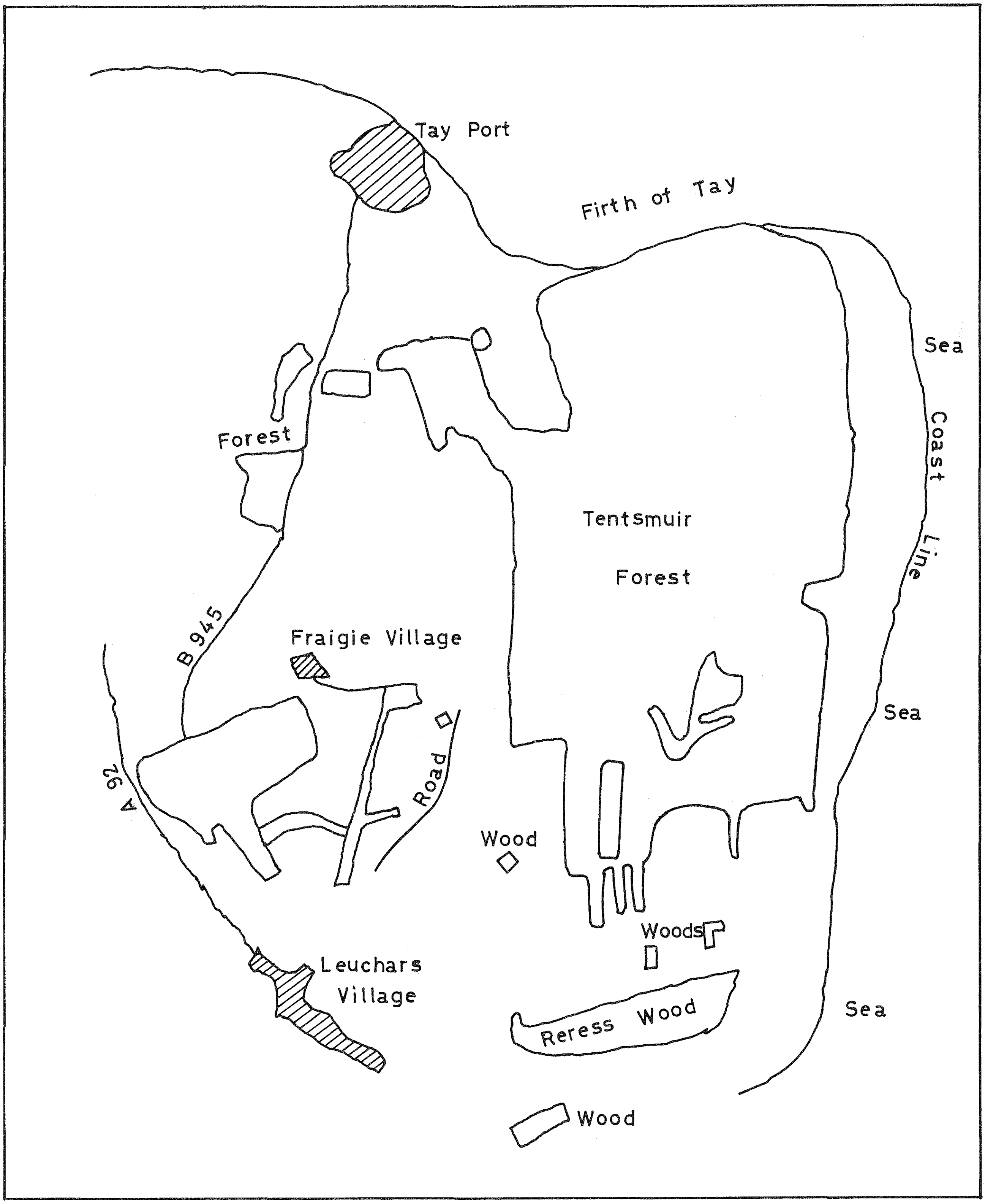

Fig. 1 : Features Plotted before Rectification

Scale : 1 : 50 000

(Traced from original Computer output)

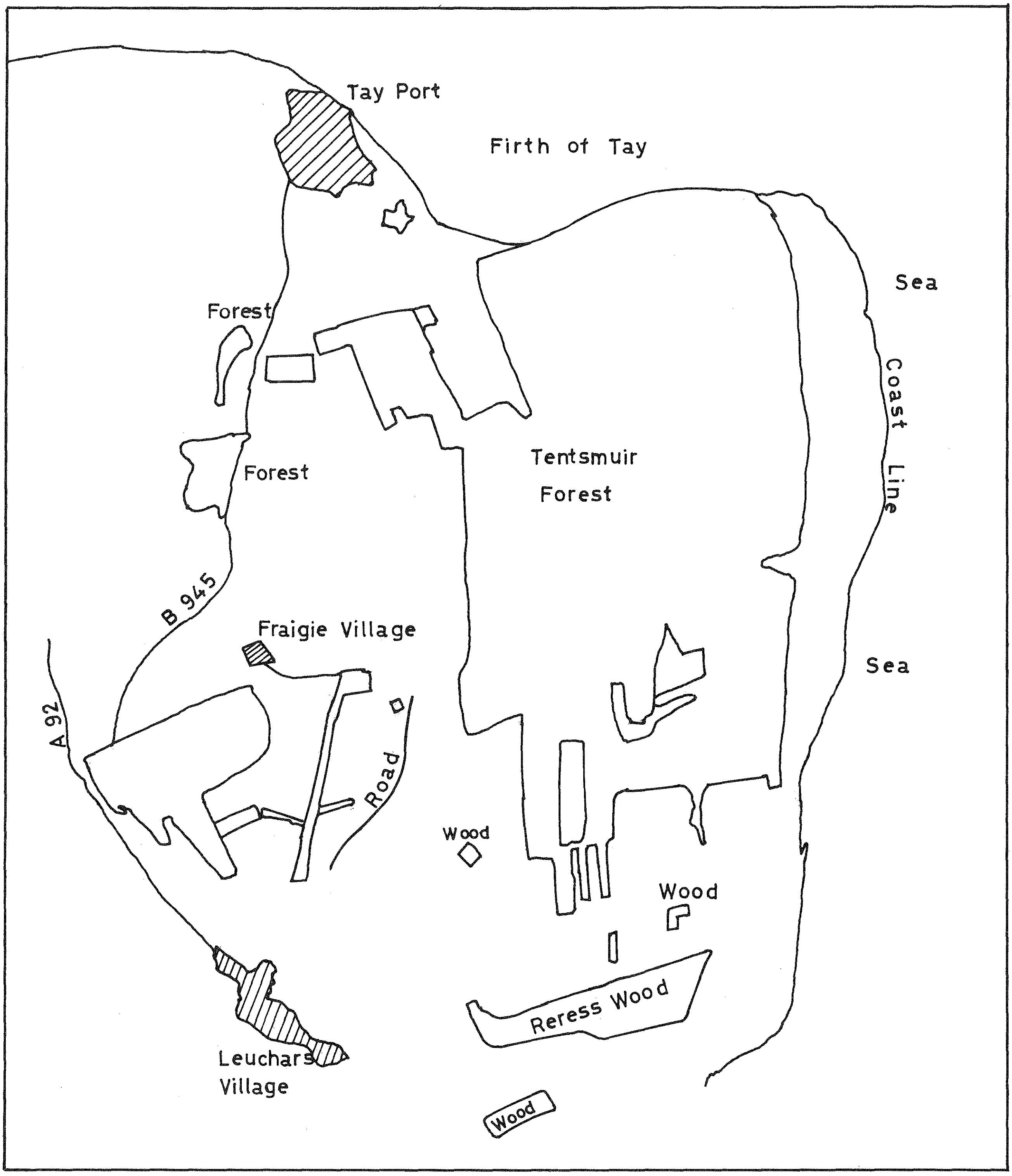

Fig. 2 : Map Plotted from Rectifier Features .
Scale : 1 : 50 000

(Traced from original Computer output)